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A Status of U-class Earth Science Instruments at JPL

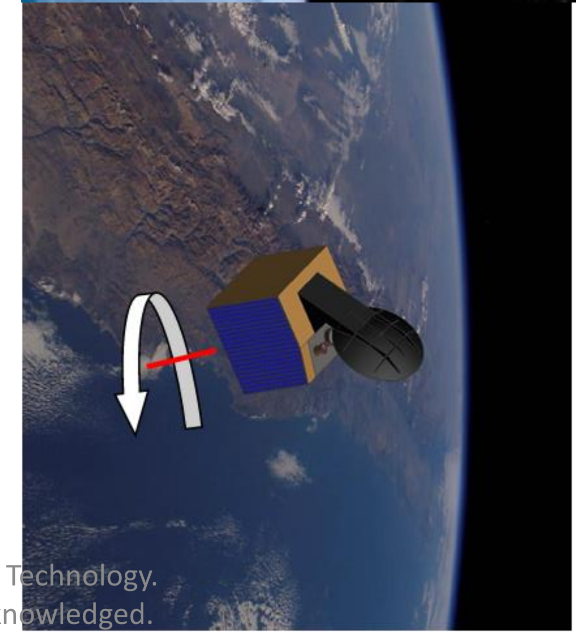
Jason Hyon

Chief Technologist, ESTD

April 24, 2017

Role of Cubesat for Science

- Objective: Can we do a meaningful science missions with these caveats?
  - Provide vertical and horizontal profile measurements of trace gases and cloud/aerosol, vegetation, and topography/tomography (1km)
  - Cost reduction (10X)
  - Provide frequent revisit time for timely observation (20-30 minutes)
  - Miniaturize instruments to 1-6 U (20x10x30cm) for CubeSat and hosted payloads



– Pre-Decisional Information -- For Planning and Discussion Purposes Only

Complexity of Understanding Weather Science – Need for multiple measurements

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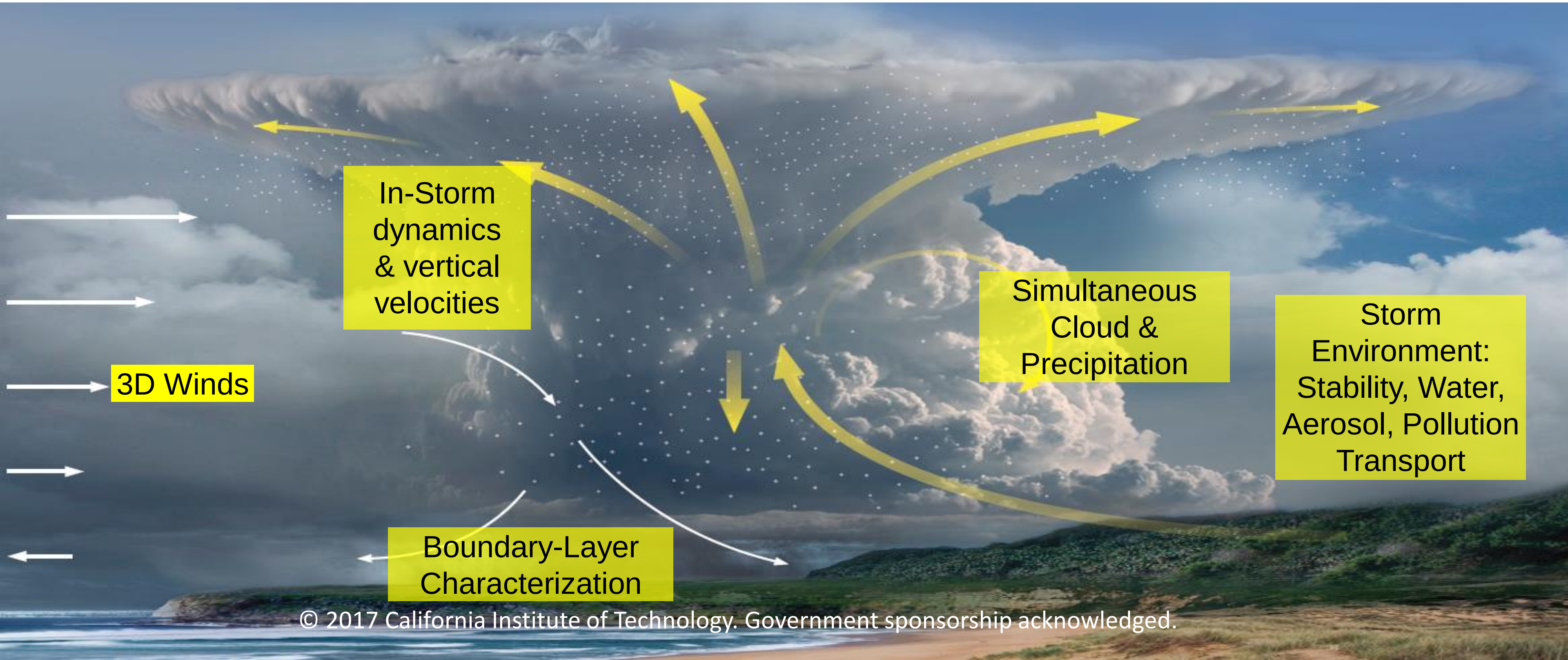
- Constellations or GEO to monitor **storm evolution**
- Higher spatial resolutions to capture **mesoscale structure**
- Capture **microphysical processes** key to precipitation growth
- Advancing technology to characterize the atmospheric **boundary-layer**
- Improved atmospheric profiling to characterize the **storm environment**
- Characterizing storm dynamics and extremes with **Doppler radar**
- **Miniaturization** of sensors for **cubesats**, constellations and lower costs



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Compact Instrument Development For Cubesat

Initial Release

October 24, 2012

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CONTRIBUTIONS

Matthew Bennett – Cubesat Spacecraft & Mission Concepts

Shannon Brown – Radiometer Mission Concepts

Tom Cwik – Identification of Existing Opportunities (OCT)

Jeffrey Dickson – Advanced Radiometric & Gravity Sensing Instrument

Raymond Ellyin – Systems Engineering & Development

Anthony Freeman – Mission Concept Formulation

Gani Ganapathi – Thermal Systems

Andrew Gray – OCT Technology Development

Jason Hyon – Strategic Planning & Editor

Eastwood Im – ESTO Technology Development

Andrew Klesh – Spacecraft Capabilities

Carol Lewis – SBIR & Other Funded Developments

Colleen Marrese-Reading – Avionics

Michael Mercury – Spacecraft Capabilities

Pantazis Mouroulis – Spectrometers & Mission Concepts

Alina Moussessian – Radar, Calibration, & Mission Concepts

Eva Peral – Radar Instrument

Greg Sadowy – MMIC & Micromachining

Andrew A. Shapiro – 3D Electronic Packaging

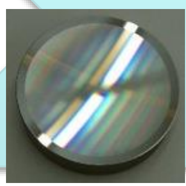
Paul Stek – Radiometer & Calibration

Mark Thomson – Deployable Antenna & Mirror

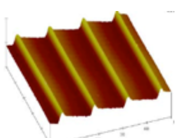
JPL's Miniaturized Weather Instruments

Visible

Miniature Dyson spectrometer



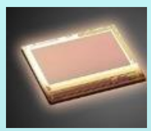
JPL e-beam grating



Infrared

JPL IR&D Wide-Field Grating Spectrometer (WFGS)

JPL BIRD MWIR Detectors



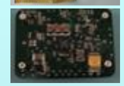
JPL Qualified Thales Cooler

Microwave

Dual-Frequency Feedhorn

MMIC Receiver including Detector

Radiometer Backend and Power Conditioning

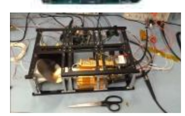


Motor and Drive Electronics

Reflector

Command and Data Handling: Onboard FPGA

MASC



Radar

SSPA & Power Combiner

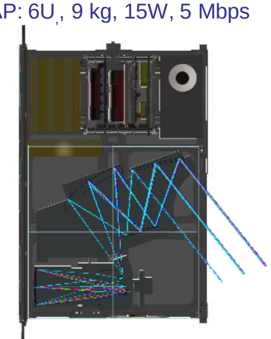
Up/Down Converter

Processing (Pulse Compression and Modulation)

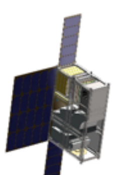
Gravity/formation Flying

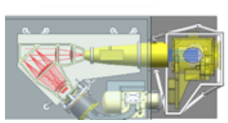
MicroGRACE Gravity Measurement
Spatial: submm accuracy
SWAP: 6U, 20 kg, 30 W, <1 Mbps

Snow and Water Imaging Spectrometer
Spatial: ±5°, 0.28 km
Spectral: 228 Bands, 350 nm – 1.65 µm
SWAP: 6U, 9 kg, 15W, 5 Mbps

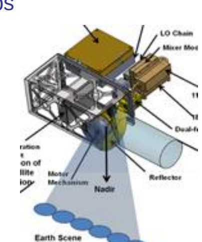


CubeSat Infrared Atmospheric Sounder (CIRAS)
Spatial: ±48.3°, 13.5 km
Spectral: 1000 Channels, 4.1-5.4 µm
SWAP: 6U, 20 kg, 30 W, 1 Mbps

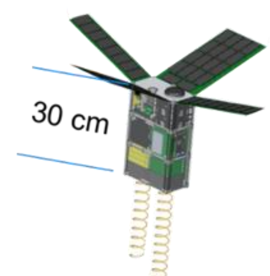




Microwave Atmospheric Sounder on CubeSat (MASC)
Spatial: ±45°, 15 km (183) – 20 km (118)
Spectral: 8 Channels: 118-183 GHz
SWAP: <0.01 m^3, 3 kg, 7 W, 10 kbps



RaInCube: Precipitation Profiler
Spatial: 5 km (Horiz) x 250m (Vert)
Spectral: 35.6 GHz
SWAP: 6U, 20 kg, 30 W, <1 Mbps



Total Identified Here: 72kg, 112W, 8 Mbps

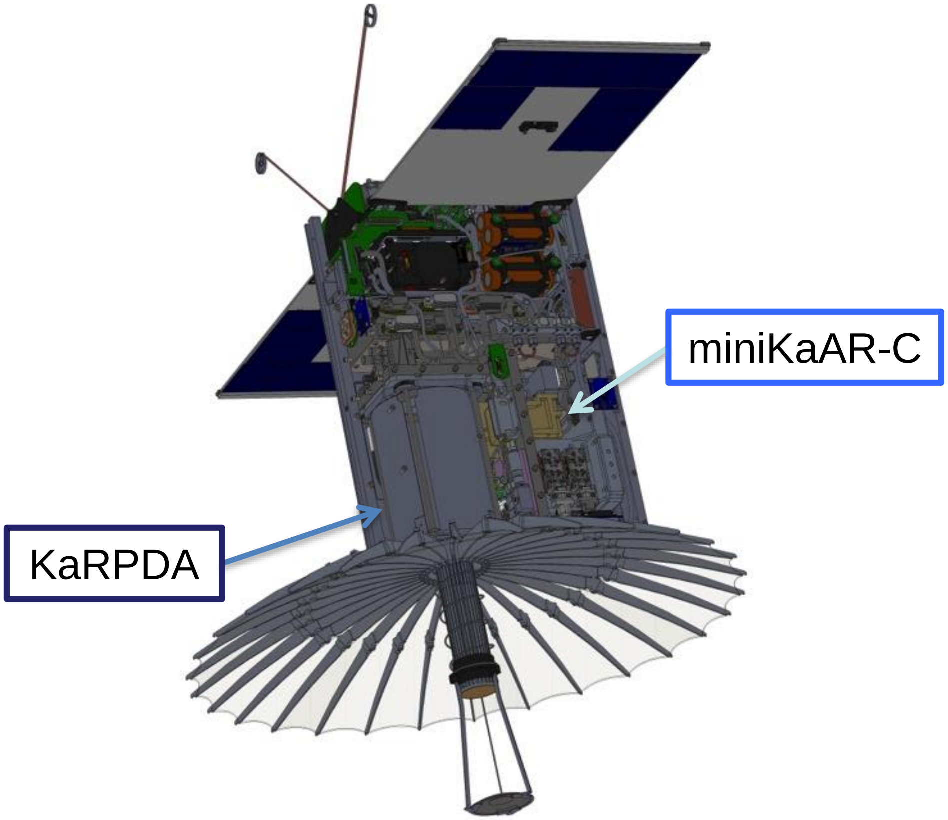
RainCube Overview

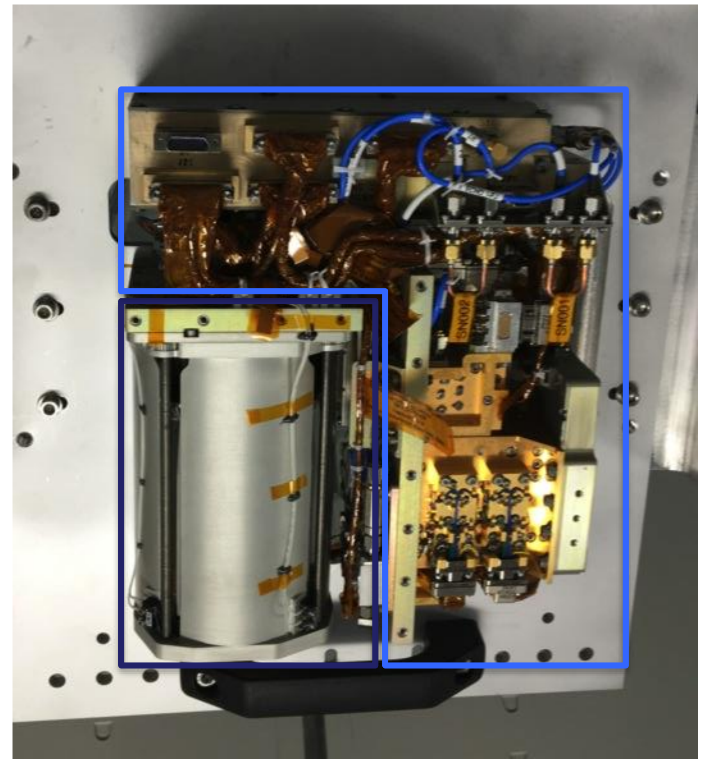
RainCube is a ***technology demonstration*** mission to enable ***Ka-band*** precipitation radar technologies on a low-cost, quick-turnaround platform.

- **ESTO InVEST Funded Task**
  - Competed mission for validating new Earth science technologies in space
  - Cost-driven mission with **$7.38 million*** total augmented budget
  - **Type II** JPL mission, no NASA classification assigned
- **Mission Objectives**
  - Demonstrate new technologies in Ka-band on a CubeSat platform
    - Miniaturized Ka-band Atmospheric Radar for CubeSats (miniKaAR-C)
    - Ka-band Radar Parabolic Deployable Antenna (KaRPDA)
  - Enable precipitation profiling radar missions for Earth Science
- **Implementation Summary**
  - 6U CubeSat (approx. 34 x 22 x 10 cm, 12 kg)
  - Deployed into LEO (approx. 400 km, 3 month mission)
  - Selected for ISS resupply launch in Spring 2018 (launch delivery NET Feb '18)

*The cost information contained in this document is of a budgetary and planning nature and is intended for informational purposes only. It does not constitute a commitment on the part of JPL and/or Caltech.

Radar Instrument





RainCube instrument is a nadir-pointed precipitation profiling radar that will demonstrate two new technologies:

- miniKaAR-C (miniaturized Ka-band Atmospheric Radar for CubeSats)
- KaRPDA (Ka-band Radar Parabolic Deployable Antenna)

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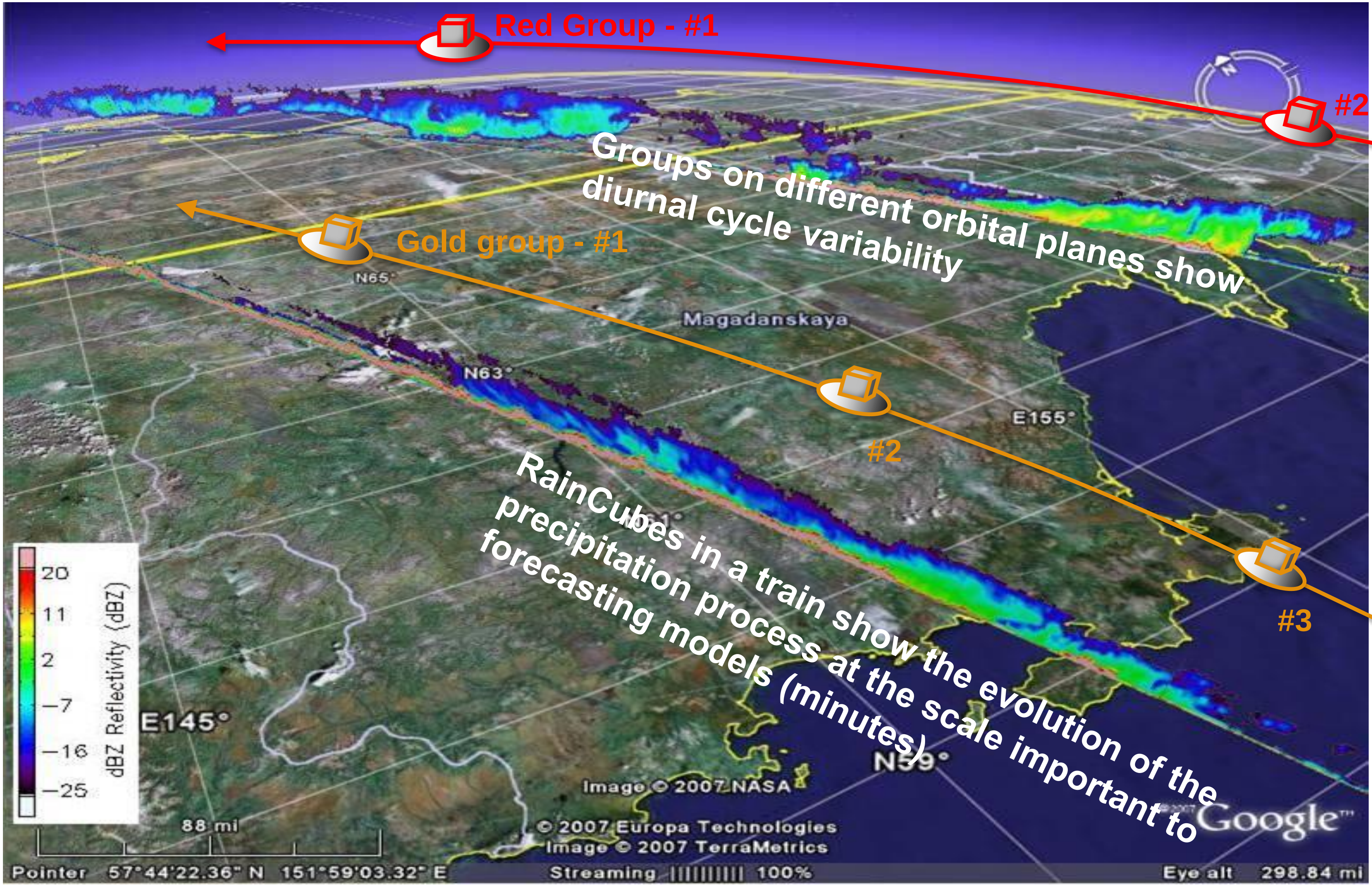
Mission Concept



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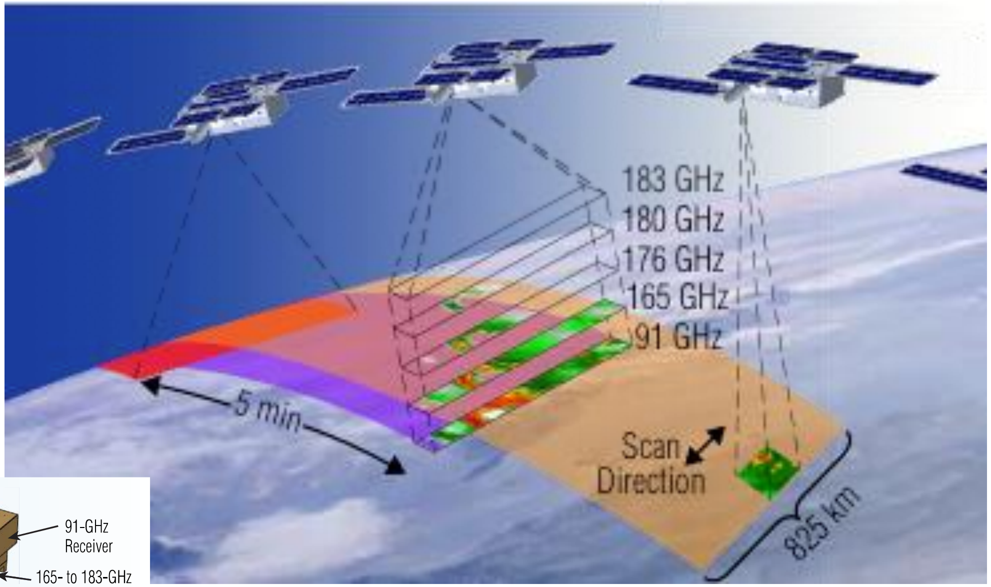
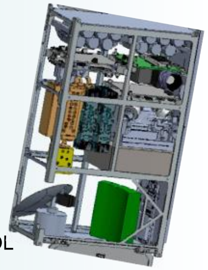
TEMPEST/MASC Mission Concept

- TEMPEST is a low Cost, CubeSat constellation of five CubeSats with identical five-frequency millimeter-wave radiometers to improve understanding of cloud and precipitation processes.

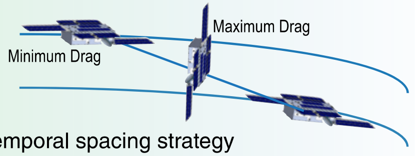


KEY FLIGHT CHARACTERISTICS

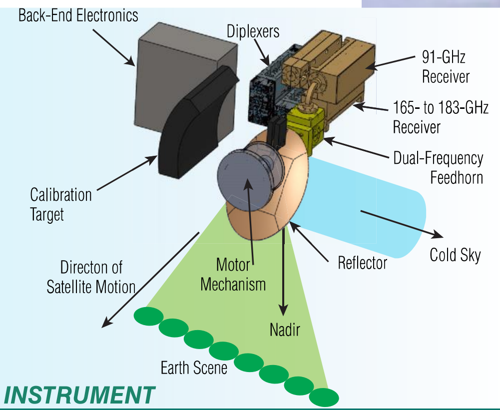
- 5 identical 6U CubeSats
  - ***Attitude:***
    - 3-axis stabilization
    - 0.13° (1σ) control
    - 0.15° (1σ) knowledge
  - ***Mass:***
    - 5.8 kg (Margin: 38%)
  - ***Power:***
    - 13 W (Margin: 23%)
    - Peak Power: 65 W EOL
  - ***Communications:***
    - 1 Mbps S-band (Margin: 22%)



- Orbital characteristic (CSLI compatible)
  - Altitude: 390 – 450 km
  - Inclination: 50°– 65°



- Temporal spacing strategy
  - Drag-adjusting attitude maneuvers used to achieve temporal separation between CubeSats



INSTRUMENT

- Millimeter-wave radiometer
  - MMIC-based
  - Self-calibrating
  - Nadir-viewing
  - Cross-track scanning
- Five-frequency direct-detection receivers at 91,165, 176, 180 and 183 GHz

Characteristic	Instrument Capability
Half-Power Beamwidth (HPBW)	3.6° (90 GHz) 1.8° (183 GHz)
Intersatellite Precision	0.6 K
Absolute Tb Accuracy	3 K

Sensor Data Records (SDRs)

- *Multiple, consecutive scans with 12 channels; brightness temperature in units of Kelvin adjusted for antenna patterns and the reference geolocation position.*

Environmental Data Records (EDRs)

- *Atmospheric Vertical Temperature Profile (AVTP)*
- *Atmospheric Vertical Moisture Profile (AVMP)*
- *Rainfall Rate (RR)*
- *Imagery*

- Pre-Decisional Information -- For Planning and Discussion Purposes Only

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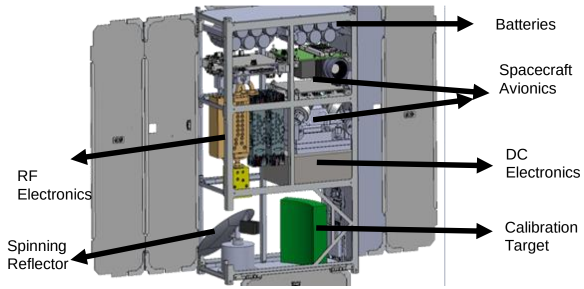
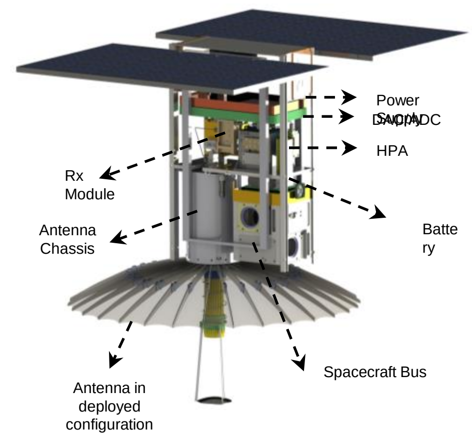
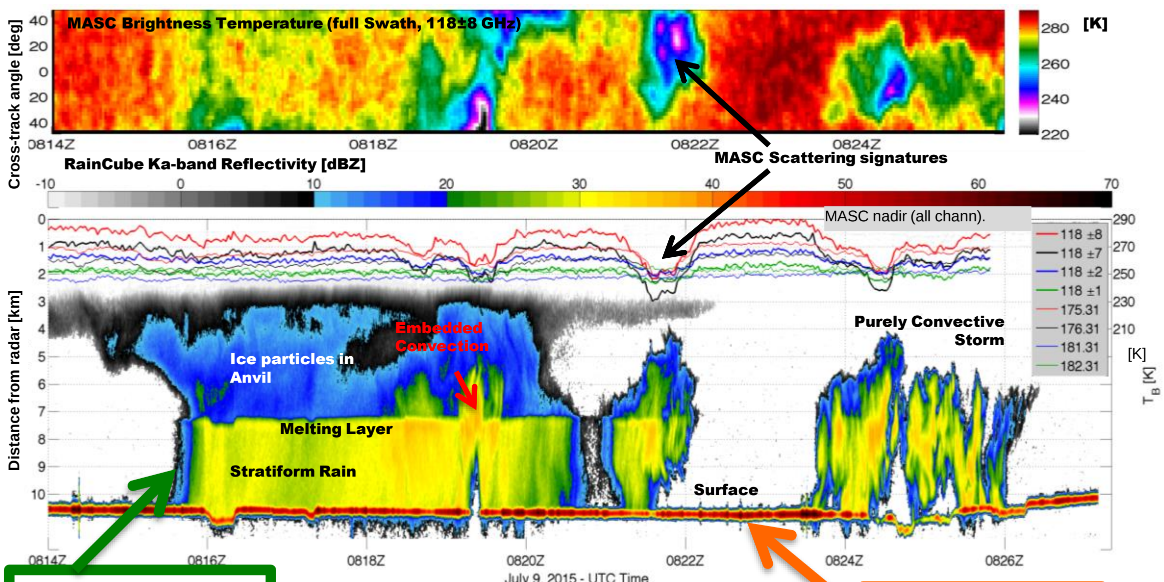
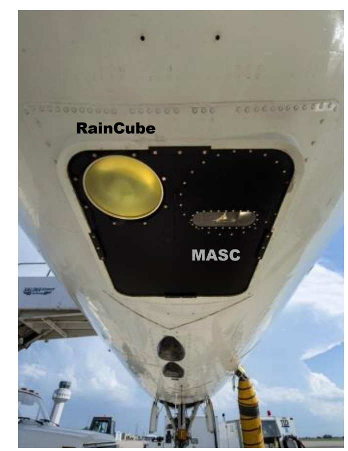
RainCube & MASC First Airborne Observations of Clouds and Precipitation during the PECAN Experiment (June-July 2015)









RainCube Sensitivity and Resolution : confirmed

RainCube Pulse Compression performance: confirmed

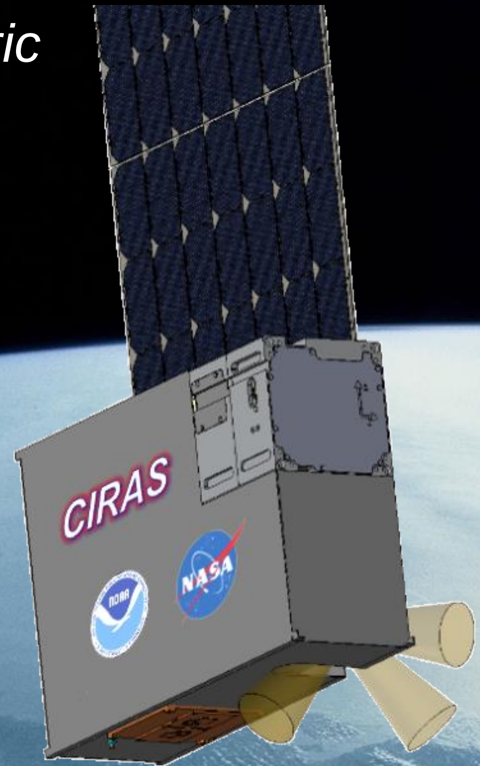
- No faults or glitches from first flight to last flight.
- Fine calibration and science analysis: in progress.
- Coordinated operations with ground based weather radars

Acknowledging:

- **AFRC**: excellent coordination and rapid implementation
- **PECAN** Science Leadership: outstanding flexible and creative collaboration
- **OU ARRC**: coordinated deployment of X-band ground based weather radars
- **Weather Focus Area** Leads: additional flight hours to PECAN for RainCube and MASC
- **Kansas City Star** picture gallery: http://www.kansascity.com/news/local/article27710704.html

*CubeSat Infrared Atmospheric Sounder (CIRAS)**

For NASA InVEST
PI: Tom Pagano (JPL)
Sponsor: NASA ESTO



CIRAS will reduce the cost of atmospheric sounding in the infrared and enable more frequent revisit times through constellations

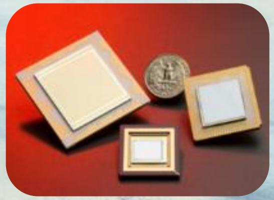
CIRAS Mission

- *Demonstrate Key Technologies needed for Infrared Instruments on CubeSats*
- *Demonstrate ability of Hyperspectral Mid IR radiance measurements to retrieve Temperature and Water Vapor Profiles*
- *Fill Coverage Gaps and Improve Timeliness of Operational IR Sounders*
- *TRL in: 5-6, TRL out: 7*
- *Build: 2016, 2017. Launch 2018-2019*

Parameter	CIRAS
Spatial	
Orbit Altitude	600 km
Pushbroom SW	1500 km, 150 km
Horizontal Res'n	13.5 km, 3km
Spectral	
Method	Grating
Band 1	4.08-5.13 µm
Spectral Resolution	1.2 cm^{-1} – 2.0 cm^{-1}
Total Channels	625
Radiometric	
NEdT (@250K)	<0.25 K
Resources	
Size	6U Cubesat
Mass	14 kg
Power	30 W
Data Rate	0.4 Mbps

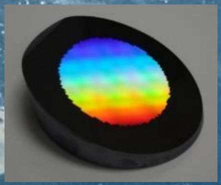
CIRAS Technologies

JPL HOT-BIRD Detector

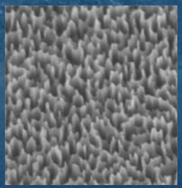


Ball Aerospace Wide Field Spectrometer

JPL Immersion Grating

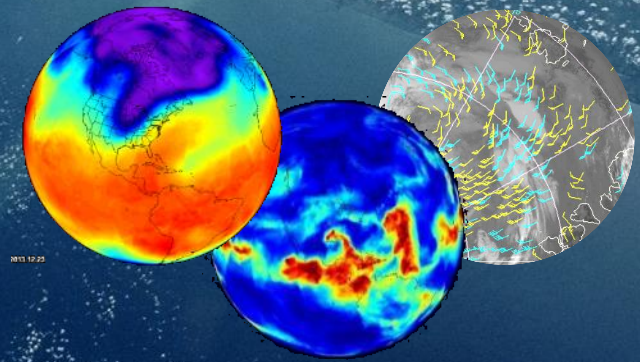


JPL Black Silicon Blackbody & Slit



CIRAS Measurements

- *Lower Tropospheric Temperature Profiles*
- *Lower Tropospheric Water Vapor Profiles*
- *Goal: Zoom Mode (3km) needed for 3D Winds*



**Patent Pending. JPL Doc. Clearance URS259870*

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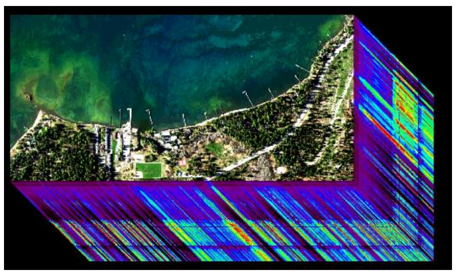
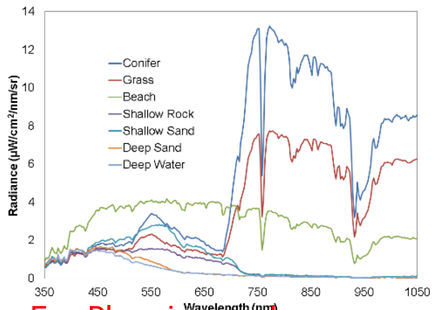
Snow and Water Imaging Spectrometer (SWIS) for coasts and snow cover

Measurement

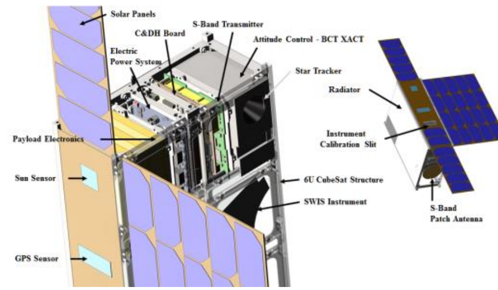
- *L1: Calibrated hyperspectral radiance at sensor*
- *L2: Hyperspectral remote sensing reflectance, R_{rs}*

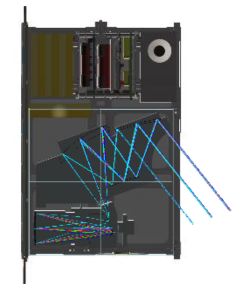




Pre-Decisional Information -- For Planning and Discussion Purposes Only

Instrument





Mass	*9 kg*
Power	*15 W*
Volume	*6U*
Data Rate	*> 5 Mbps*

Heritage Instruments

- *Hyperion on NM-EO1*
- *HICO on ISS*
- *MERIS (ESA)*
- *PRISM (airborne)*

Performance

Parameter	Hyperion	HICO	SWIS
Spectral range (nm)	400-2500	400-900	350-1650
Sampling (nm)	10	5.7	5.7
Cross-track elements	256	512	620
FOV (deg)	0.63	6.9	10
Resolution (mrad)	0.043	0.24	0.33
Uniformity (%)	60	40	95
Throughput (10^{-6} mm^2)	7.4	5.1	69
Polarization %	5	8	1.5

Technology Readiness

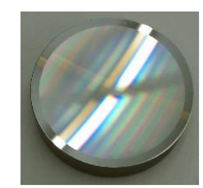
Proven Technologies

- *Broadband polarization-insensitive diffraction grating*
- *Dyson spectrometer*
- *Order-sorting filter*

Miniature Dyson spectrometer

Pending Demonstrations (: IIP 2013)*

- *High temp. HgCdTe array with custom anti-reflection coating **
- *CubeSat form factor FPIE electronics and on-board processing*
- *High data rate transmission*
- *Calibration subsystem **
- *Thermal design **



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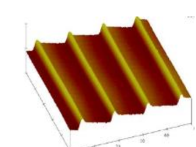

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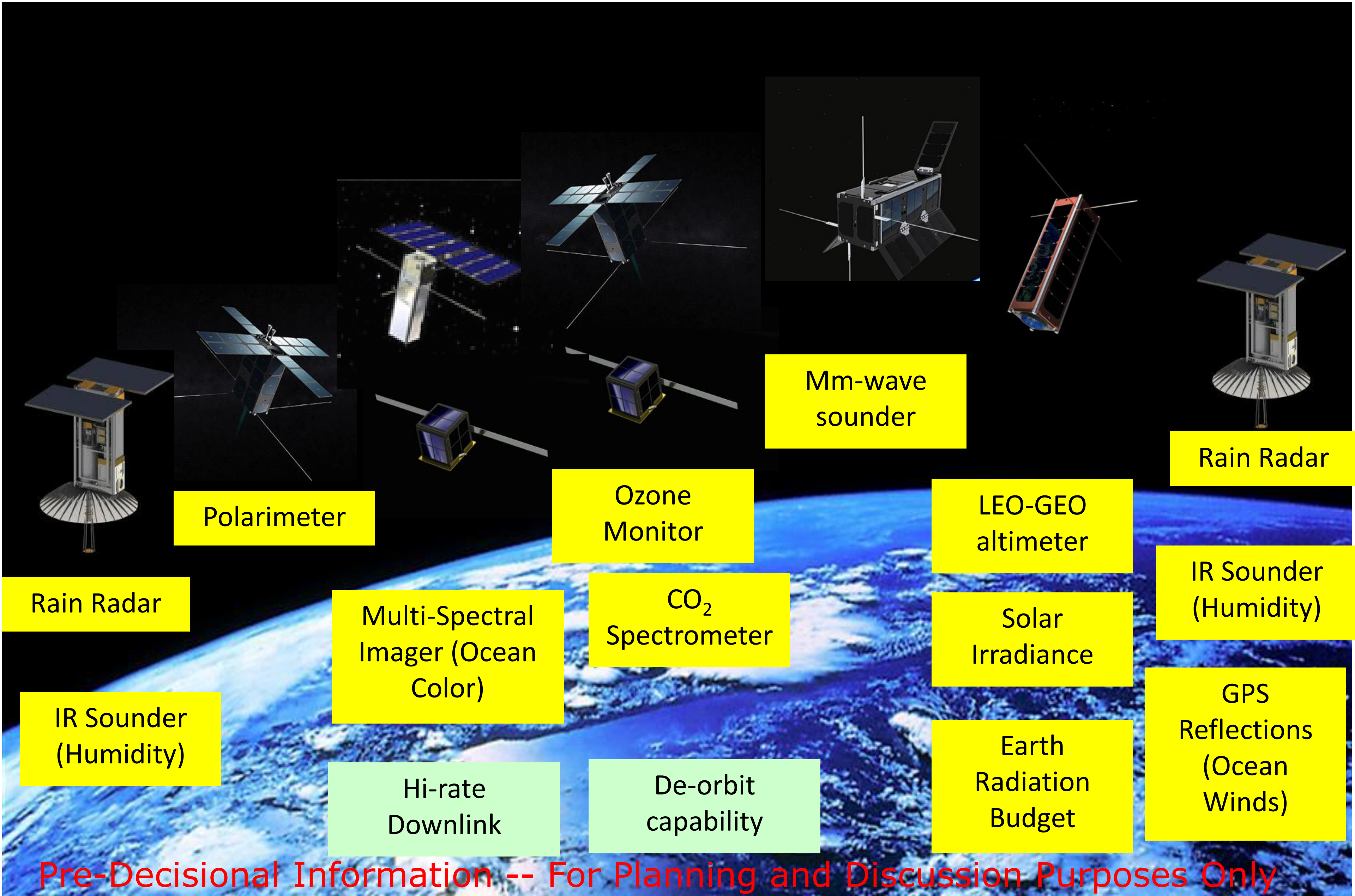
Mission Concept Trade

	Ocean focus – Cubesat	Ocean focus	Coasts focus – Cubesat	Coasts focus	Land focus	Landsat-like
Spatial Res	1 km	1 km	200 m	200 m	60 m	30 m
Global Revisit	1 day	1 day	9:30 AM + 3:30 PM Daily	9:30 AM + 3:30 PM Daily	10 day	16 day
Global Coverage each revisit	100%	100%	8%	40%	100%	100%
# of Satellites	30	4	18	4	4	12
FOV [deg]	40	40 x2	12 (36 FOR)	30	9	1.5
# of Launches	3	1	2	1	1	3
Altitude [km]	561	561	561	561	626	619
Instrument dimensions	0.01x0.02x 0.01 m	(0.01x0.02x 0.01 m) x2	0.01x0.02x 0.01 m	0.3x0.2x 0.2 m	0.6x0.45x 0.45 m	0.3x0.2x 0.2 m
# of x-track detector elements	400	600 x2	600	1600	1600	600
F stop	F 1.8	F 1.8	F 1.8	f 1.8	f 1.8	f 3
Spacecraft class	Cubesat	SSTL 150 class	Cubesat	SSTL 150 class	SSTL 300 class	SSTL 300 class

Pre-Decisional Information -- For Planning and Discussion Purposes Only

Single Cube-Train Concept



Summary

- Define science mission concepts only CubeSat can solve with the lower cost
  - Temporal sampling and/or heterogeneous instruments
- Miniaturized science instruments that are fully self calibrated are essential
- Establishment of a reliable ground network
- Class C mission – 3 year life
  - Class C instrument with SmallSat
- Industry driven – propulsion, communication, avionics, power
- We are looking to fill the space through an international partnership